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THERMAL TESTING OF A SIMULATED IRRADIATED FUEL TRANSPORTATION CASK UNDER NORMAL OPERATING CONDITIONS

Report No 84-277-K

D. Taralis
Engineer
Applied Structural and Solid
Mechanics Section
Mechanical Research Department

ABSTRACT

A full scale experimental study has been carried out to investigate the thermal behaviour of a simulated two-module rectangular cask under normal operating conditions. Temperature measurements were made with air as well as with air-water in the cask cavity. The effects of an impact limiter on the maximum module tube temperature and also the effects of a weather cover were investigated. The maximum fuel sheath temperature was determined using the present temperature measurements and previous experimental results obtained from a one module tube/fuel bundle assembly. Based on the results of this study it is possible to ship irradiated fuel at low decay heat levels without exceeding the desired temperature limit of 200°C for an air filled cavity.

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EXECUTIVE SUMMARY

THERMAL TESTING OF A SIMULATED IRRADIATED FUEL TRANSPORTATION CASK UNDER NORMAL OPERATING CONDITIONS

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A simulated two-module rectangular cask has been built and tested with air and air-water in the fuel cavity at various heat imput levels. The main objective was to establish fuel temperatures and cavity pressure. The results of this study include:

1. Steady state temperatures of the module tubes with and without an impact limiter and with air in the cask cavity.

2. Steady state temperatures of the module tubes and cask cavity pressure without an impact limiter and with air-water in the fuel cavity.

3. Steady state temperatures of the module tubes with a weather cover and with air in the cavity.

Based on the results of this study the maximum fuel sheath temperature for an air-filled cavity was below the limit of 200°C. For a water-filled and drained cavity the cavity pressure was far below the maximum allowable pressure of 700 kPa during normal operating conditions.

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To Mr. H.N. Isaac
Design & Development Division
H10A27

THERMAL TESTING OF A SIMULATED IRRADIATED FUEL TRANSPORTATION CASK UNDER NORMAL OPERATING CONDITIONS

1.0 INTRODUCTION

The present study is an extension of a previous theoretical study related to the thermal analysis of an irradiated fuel transportation cask under normal operating conditions/1/. The main objectives of this study are:

i) To measure the temperature of the hottest module tube within the cavity of a two-module rectangular cask.

ii) To determine the maximum fuel sheath temperature using the temperature of the hottest module tube and previous temperature measurements/2/ obtained from a one module tube/fuel bundle assembly.

iii) To assist in the development of the analytical tools.

One of the main concerns of the study was to ensure that the maximum fuel sheath temperature for an air-filled cavity will not exceed the desired limit of 200°C above which oxidation of any exposed uranium dioxide fuel may be significant.

This report describes the experimental apparatus and the instrumentation used, presents the temperature results of the tests and states the main conclusions of the study.

2.0 EXPERIMENTAL APPARATUS

This section describes the test apparatus that has been used to study the thermal behaviour of a two-module rectangular cask under normal operating conditions.

2.1 Simulated Cask

Figure 1 shows a schematic diagram of the simulated cask. It can accommodate up to two fuel storage modules with horizontal clearance of 90 mm on each side and a vertical clearance of 110 mm at the top. There are two openings at the top of the vessel for passing through the heater cables and thermocouple wires. A drain of 25.4 mm has been provided near the bottom. The vessel has been designed according to the ASME pressure vessel code Section VIII, Division 1 for 700 kPa and 150°C. The total weight of the empty vessel including the cover (See Figure 2) is approximately 7 tons.

2.2 Fuel Storage Modules

Figure 3 shows an isometric view of a fuel storage module. Two of these modules were placed within the cask cavity. One such module consists of 48 tubes and each tube accommodates two fuel bundles. The module tubes are arranged in equilateral triangular arrays with pitch to diameter ratio of 1.2. A photograph of the two fuel modules is shown in Figure 4. Two more photographs showing the fuel modules in the cask cavity are presented in Figure 5.

2.3 Simulated Fuel Bundles

Since the objective was to measure the temperature of the module tubes an accurate modelling of the actual fuel bundles was considered unnecessary. However the flow resistance of the simulated fuel bundles was broadly equivalent to real bundles. Each simulated bundle was made up of 7 tubes (19 mm dia) arranged as shown in Figure 6. The decay heat was simulated using Chromalox heaters one for each module tube.

2.4 Power Supply

To provide the required heat input to the simulated cask a power supply of 200 VAC single phase was installed (See Figure 7). The heat input was controlled through a three-stack variable transformer with voltage output from 0-230 VAC. The total power that could be handled by the variac was approximately 20 kW. All electric heaters were connected in parallel and through eight circuit breakers (12 heaters/breaker).

2.5 Weather Cover

Figure 8 shows the basic configuration of a weather cover that will be placed over the cask during transportation. As can

be seen from this figure a clearance of 284 mm between the cover and the cask wall has been provided. Near the bottom of the cover there are several openings on each side to allow air flow for cooling purposes. The simulated weather cover was made by building a wooden frame and attaching a thin sheet of masonite around it.

3.0 INSTRUMENTATION

The instrumentation used for making the required measurements is described below.

3.1 Thermocouples

The temperature of the module tubes within the cask cavity as well as the cask wall temperature were measured using Chromel-Alumel (Type K) thermocouples. The location of the thermocouple junctions and their identification numbers are shown in Figure 9. As can be seen from this figure there are no thermocouples near the central region of each module due to difficulties of installing thermocouples at these areas.

3.2 Power Meter

The power input to the electric heaters was measured using a very high precision power meter made by Weston Co. Since the maximum current capacity of the meter was below the maximum current required in the tests a current transformer with ratio 1 to 20 was used.

3.3 Pressure Gauges

Two pressure gauges of the dial type were installed on the pressure vessel. One pressure gauge was used to detect low pressures in the range 0-100 kPa and the other in the range 50-800 kPa.

3.4 Data Acquisition System

In recording the temperature distribution within the cask cavity the AUTO DATA 10 acquisition system was used. The system is suitable for transient as well as steady state measurements and has the capability of accepting up to 260 different inputs. The system is very flexible allowing each channel to be programmed to a different type of thermocouple (7 types available). The temperature measurements were recorded on tape as well as on paper.

4.0 MODULE TUBE TEMPERATURE RESULTS

The steady state module tube temperature measurements at various heat input levels are presented and discussed below. The following tests were carried out:

i) air tests without impact limiter
ii) air tests with impact limiter
iii) air-water tests without impact limiter
iv) air tests with impact limiter and a weather cover

To minimize the heat loss to the ground a layer of plywood-styrofoam was placed under the bottom of the cask.

4.1 Air Tests Without Impact Limiter

Figure 10 shows the simulated cask without an impact limiter. The temperature measurements with air in the cask cavity are shown in Figures 11 through 14. These figures reveal that the maximum temperature of the module tube occurs near the centre of the top module. The exact location though cannot be determined because there are not sufficient thermocouples in that region. Examination of the temperature distributions reveals that radiation heat transfer is also contributing to the overall heat transfer mode. Normally in free convective flows where radiation effects are negligible the highest temperature would be expected to be near the top.

4.2 Air Tests With Impact Limiter

These tests still correspond to air within the cask cavity but with an impact limiter at the top as shown in Figure 15. The impact limiter was made of styrofoam of sufficient thickness for approximating ideal insulating conditions. The results from these tests are shown in Figures 16 through 19. As can be seen from these figures the temperature variation along the vertical wall of the cask is quite pronounced. In the tests without impact limiter the temperature along the vertical direction was nearly constant. The effect of the impact limiter at the top of the cask is, of course, higher temperatures. For 20 W/bundle there is a temperature increase of about 14°C (from comparison of Figure 14 and Figure 19).

4.3 Air-Water Tests Without Impact Limiter

The purpose of these tests was to simulate a more realistic situation by considering different residual amounts of water within the cask cavity. Such a situation arises when the cask is loaded with irradiated fuel under water. The loaded cask is

then removed from the storage bay and subsequently drained. As the cask heats up, some of the residual water may turn into steam and thus an air-steam mixture within the cask cavity could be present.

Three tests with three different amounts of water within the cask cavity were investigated. Figure 20 shows the temperature distribution for 20 litres of water in the cask at 20 W/bundle. A comparison of this figure with Figure 14 shows that the presence of 20 litres of water in the cask cavity has the effect to lower the module tube temperatures only by a few degrees °C. The results for the other two amounts of water (60 litres and completely filled and drained cavity) are shown in Figures 21 and 22 for a heat input of 30 W/bundle. These figures also show that the effect on the temperature distribution for having different amounts of water in the cask cavity is not very significant.

4.4 Air Tests With an Impact Limiter and a Weather Cover

To study the effects of a weather cover over the cask on the fuel temperature only one test at 20 W/bundle was carried out. The temperature distribution for this test is shown in Figure 23. A comparison of this figure with Figure 19 (same conditions but without cover) indicates that the presence of the weather cover does not change the temperature distribution appreciably.

5.0 MAXIMUM FUEL SHEATH TEMPERATURE

The maximum fuel sheath temperature was obtained using the present temperature results for the hottest module tube and the experimental results of a previous study/2/. Figure 24 shows these results as a function of the heat input level. Therefore the maximum fuel sheath temperature within a two-module cask was determined from the following equation:

$$T_F = (T_T)_{\text{present results}} + (T_F - T_T)_{\text{previous results}}$$

where:

T_T = temperature of hottest module tube
T_F = maximum fuel sheath temperature

Table 1 shows the maximum fuel sheath temperature at various decay heat levels for the conditions investigated.

6.0 CASK CAVITY PRESSURE

Cask cavity pressures have been obtained for two air-water tests both at a heat input level of 30 W/bundle. The cavity pressure corresponding to 60 litres of water in the cask was 42 kPa (see Figure 21). For the completely filled and drained cask the cavity pressure was 50 kPa (see Figure 22). These tests indicate that under normal operating conditions the cavity pressure will be much lower than the maximum allowable pressure of 700 kPa. For tests with heat input levels at 20 W/bundle or less the cavity pressure was very low and difficult to obtain.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The results of this study described in the previous section reveal the following:

a) It is possible to ship irradiated fuel at low decay heat levels (5 to 10 years old fuel) without exceeding the desired limit of 200°C for an air filled cavity.

b) The presence of a given amount of water within the cask cavity has the effect to lower the maximum module tube temperature by a small amount.

c) For a water-filled and drained cavity the cavity pressure was 50 kPa (See Figure 22) which is far below the maximum allowable pressure of 700 kPa during normal operating conditions.

d) Providing a weather cover over the cask has a minor effect on the temperature distribution within the cask.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Mr. K.E. Nash from Nuclear Materials Management Department for his cooperation and useful discussions throughout the progress of this work. Messrs R.W. Wolfendale and O.C. Sonstenes of the Research Division are also greatly acknowledged for their high involvement in designing, building and setting up the experimental apparatus and carrying out the test program.

Approved By:

G.J. Clarke
Manager
Mechanical Research Department

Submitted By:

D. Taralis

D. Taralis
Engineer
Applied Structural & Solid Mechanics Section

DT:sc:ds

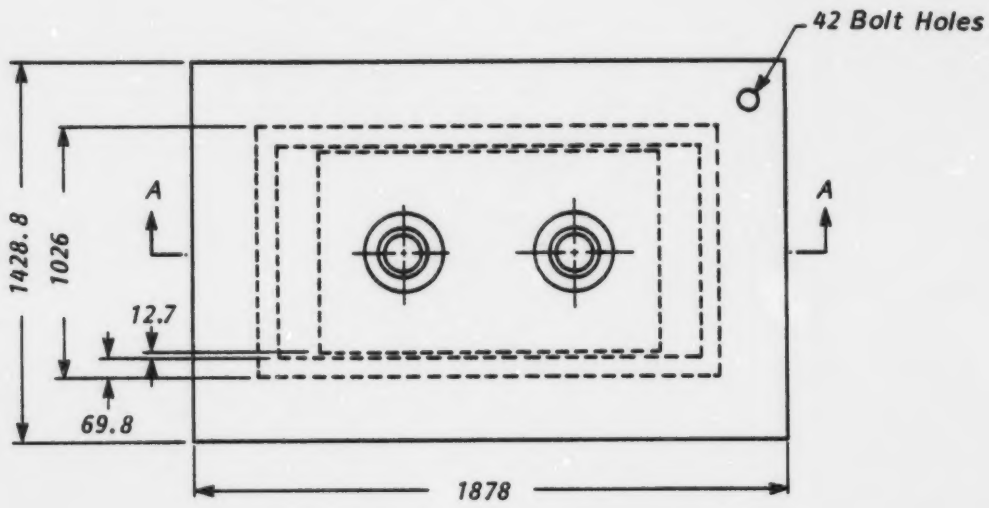
Done for JAC.

84-277

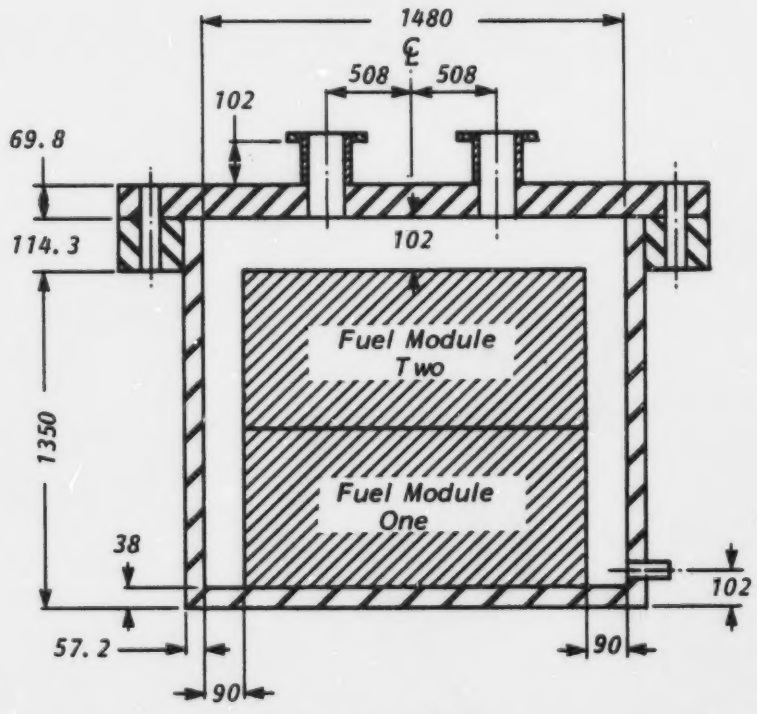
REFERENCES

1. Taralis, D., "Thermal Analysis for the Design of an Irradiated Fuel Transportation Cask Under Normal Operating Conditions", Ontario Hydro Research Division Report No 83-221-K, May 1983.

2. Taralis, D., "Thermal Testing of Irradiated Fuel Storage Module Tubes in Water and Air", Ontario Hydro Research Division Report No 80-254-K, July 1980.



Plan View



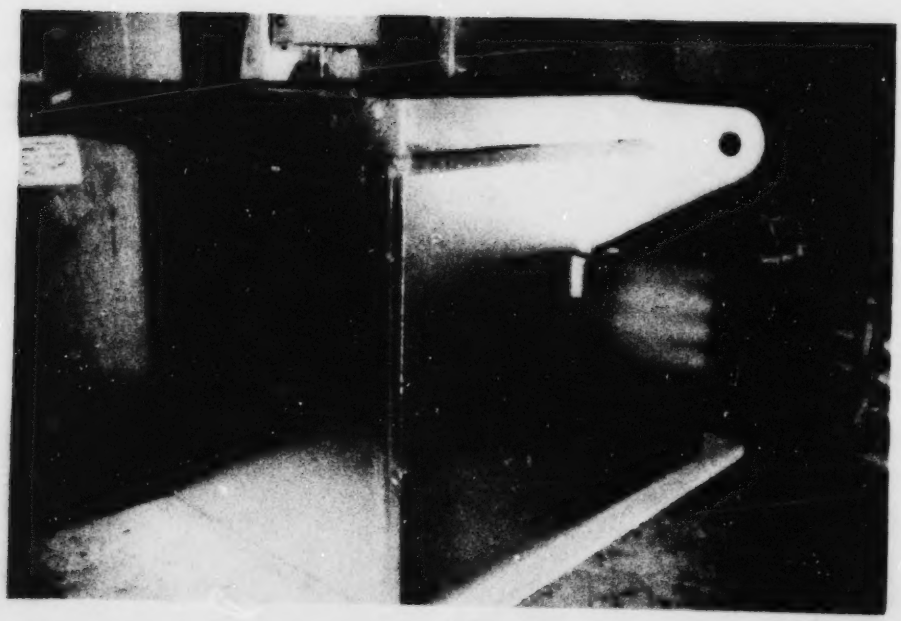
Section A-A

All Dimensions are in mm

FIGURE 1

SCHEMATIC DIAGRAM OF THE SIMULATED CASK

Cover



Vessel

FIGURE 2
PHOTOGRAPH OF THE SIMULATED CASK

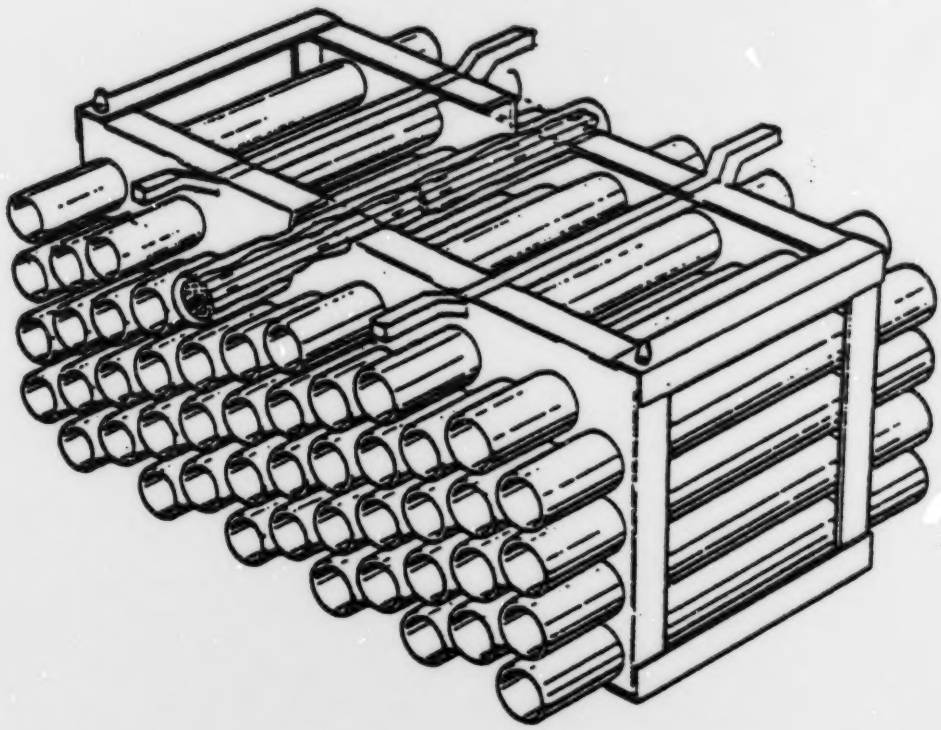
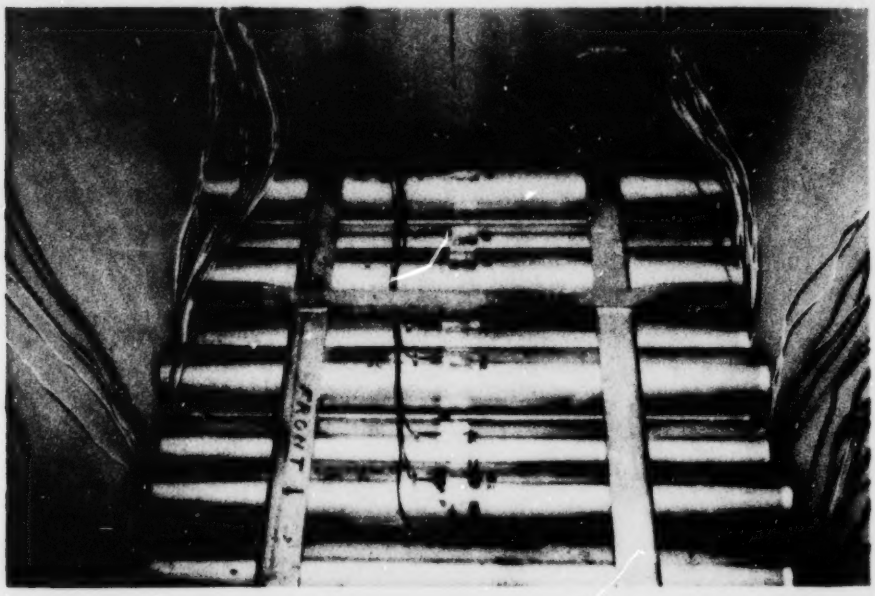


FIGURE 3

IRRADIATED FUEL STORAGE MODULE
(1.29 m x 0.99m x 0.6 m)

FIGURE 4
PHOTOGRAPH OF THE TWO FUEL MODULES

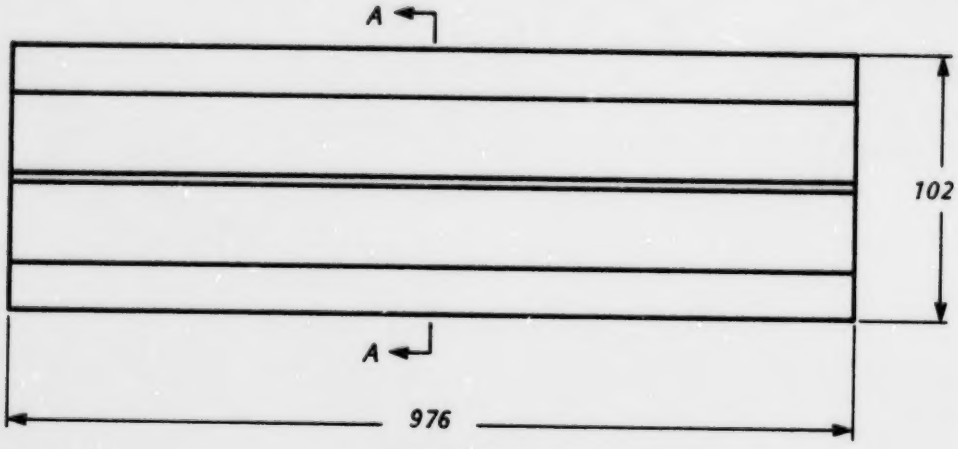


Module One

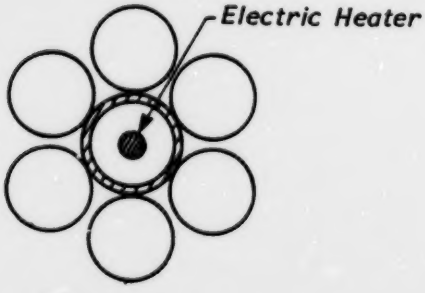
Module Two

FIGURE 5

PHOTOGRAPH OF FUEL MODULES
WITHIN CASK CAVITY



Side View



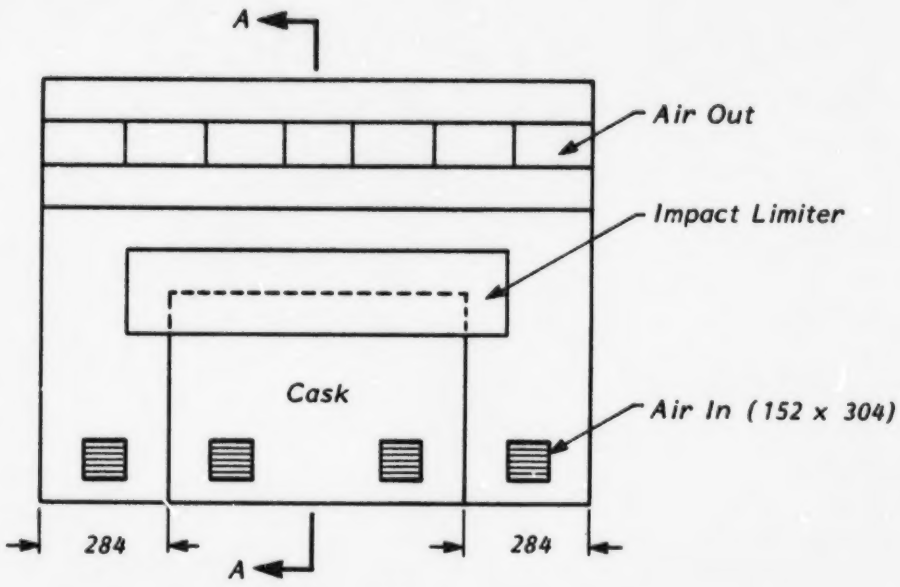
Section A-A

All Dimensions in mm

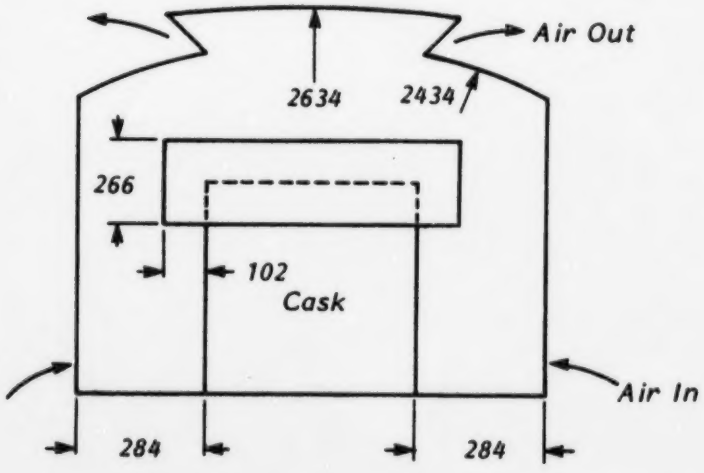
FIGURE 6
SIMULATED TWO-FUEL BUNDLE

FIGURE 7

POWER SUPPLY FOR HEAT INPUT
TO SIMULATED CASK



Side View



Section A-A

All Dimensions in mm

FIGURE 8

SCHEMATIC DIAGRAM OF WEATHER COVER

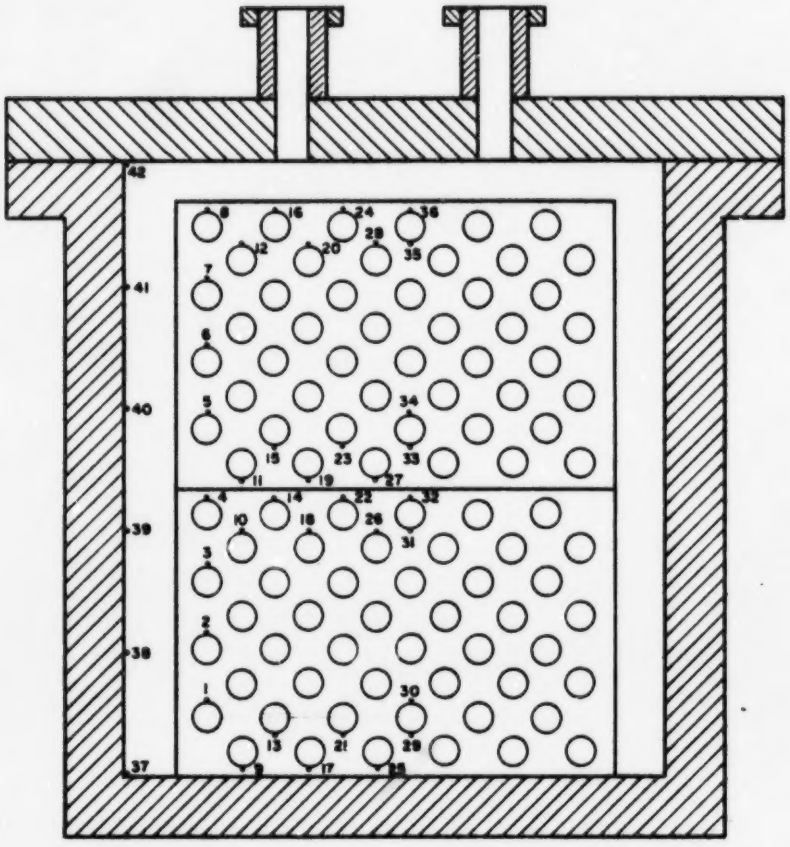


FIGURE 9
THERMOCOUPLE LOCATIONS

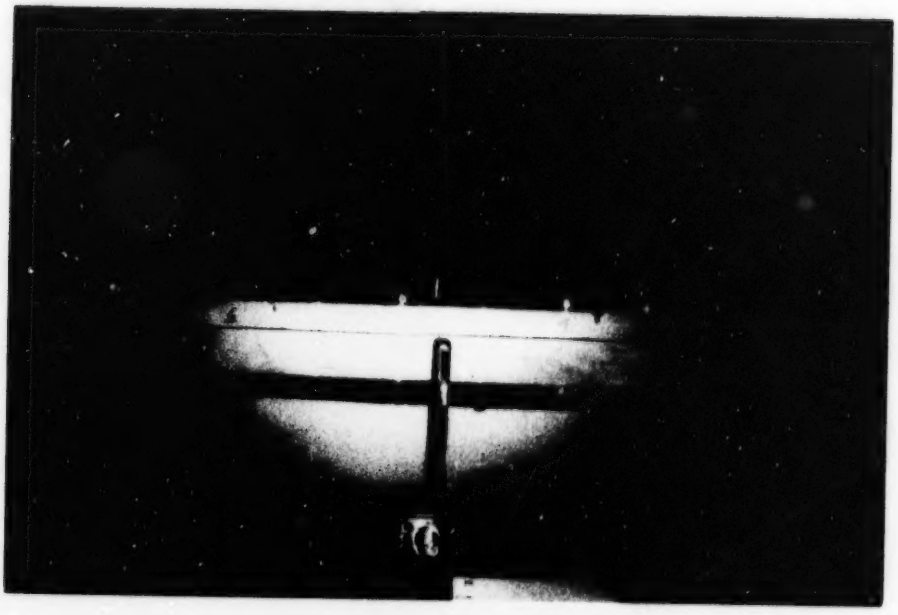
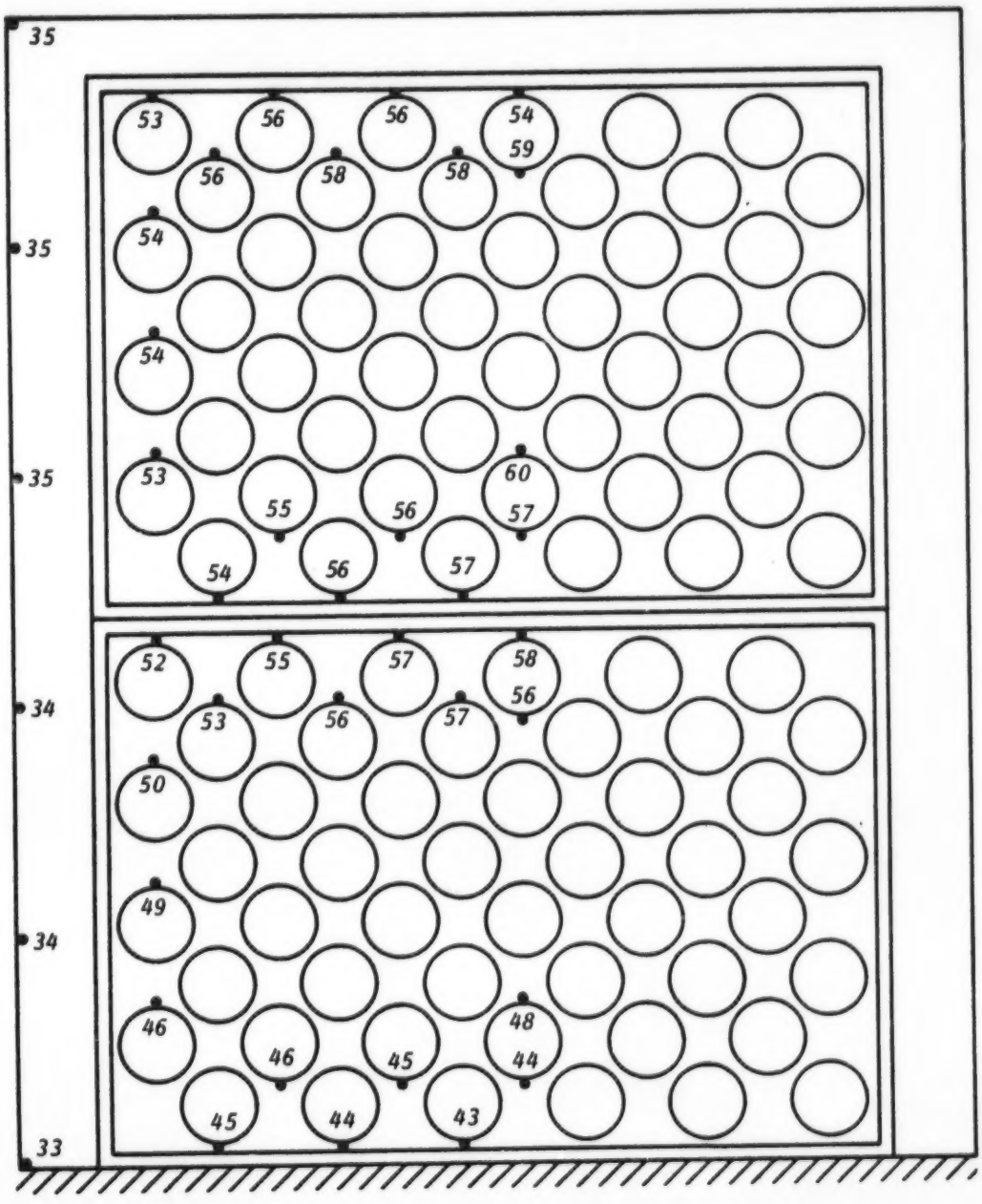


FIGURE 10
SIMULATED CASK WITHOUT IMPACT LIMITER



Ambient Temperature = 21 °C

FIGURE 11

TEMPERATURE MEASUREMENTS (°C) AT 5 W/BUNDLE WITH AIR AND NO IMPACT LIMITER

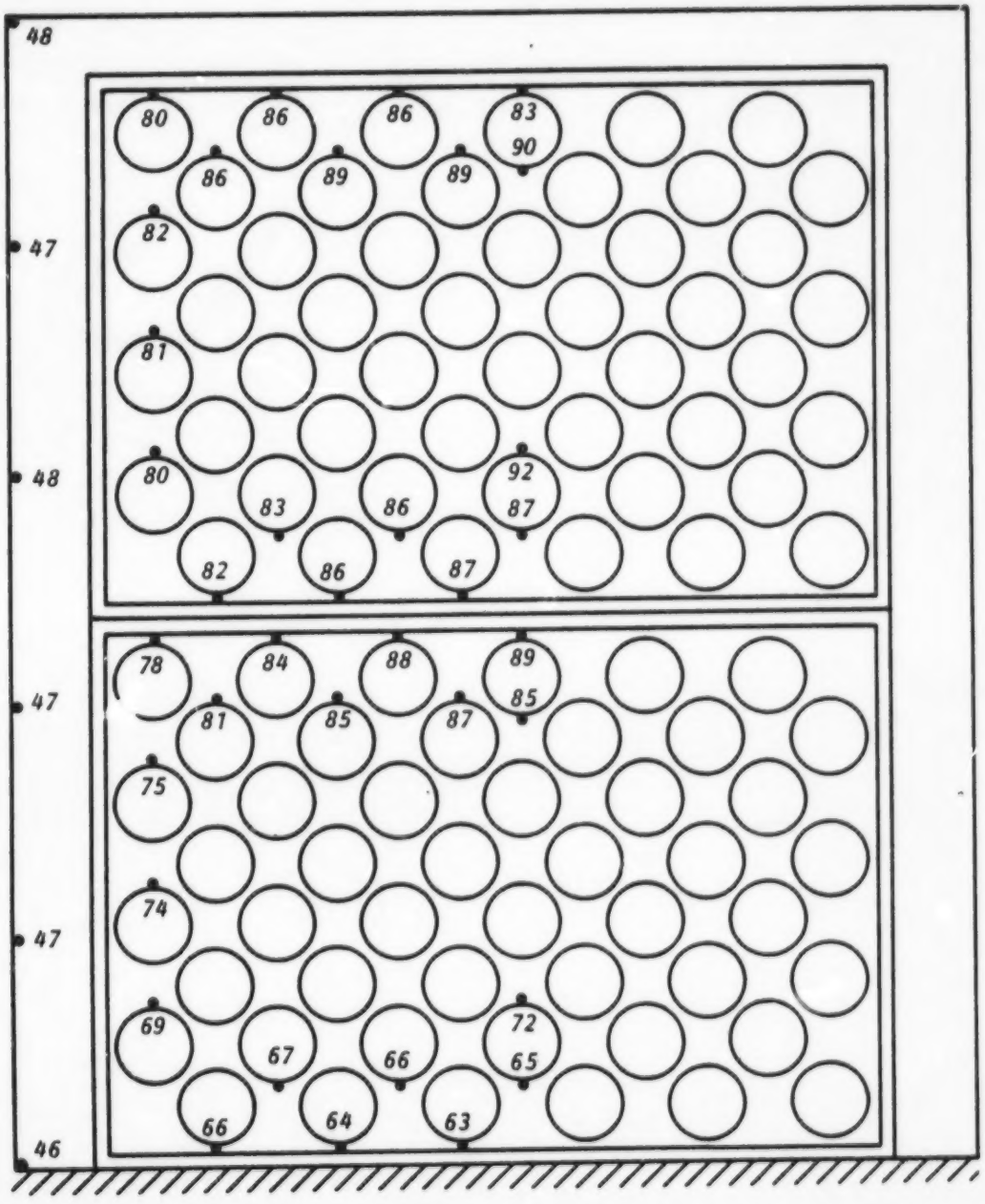


FIGURE 12

TEMPERATURE MEASUREMENTS (°C) AT 10 W/BUNDLE
WITH AIR AND NO IMPACT LIMITER

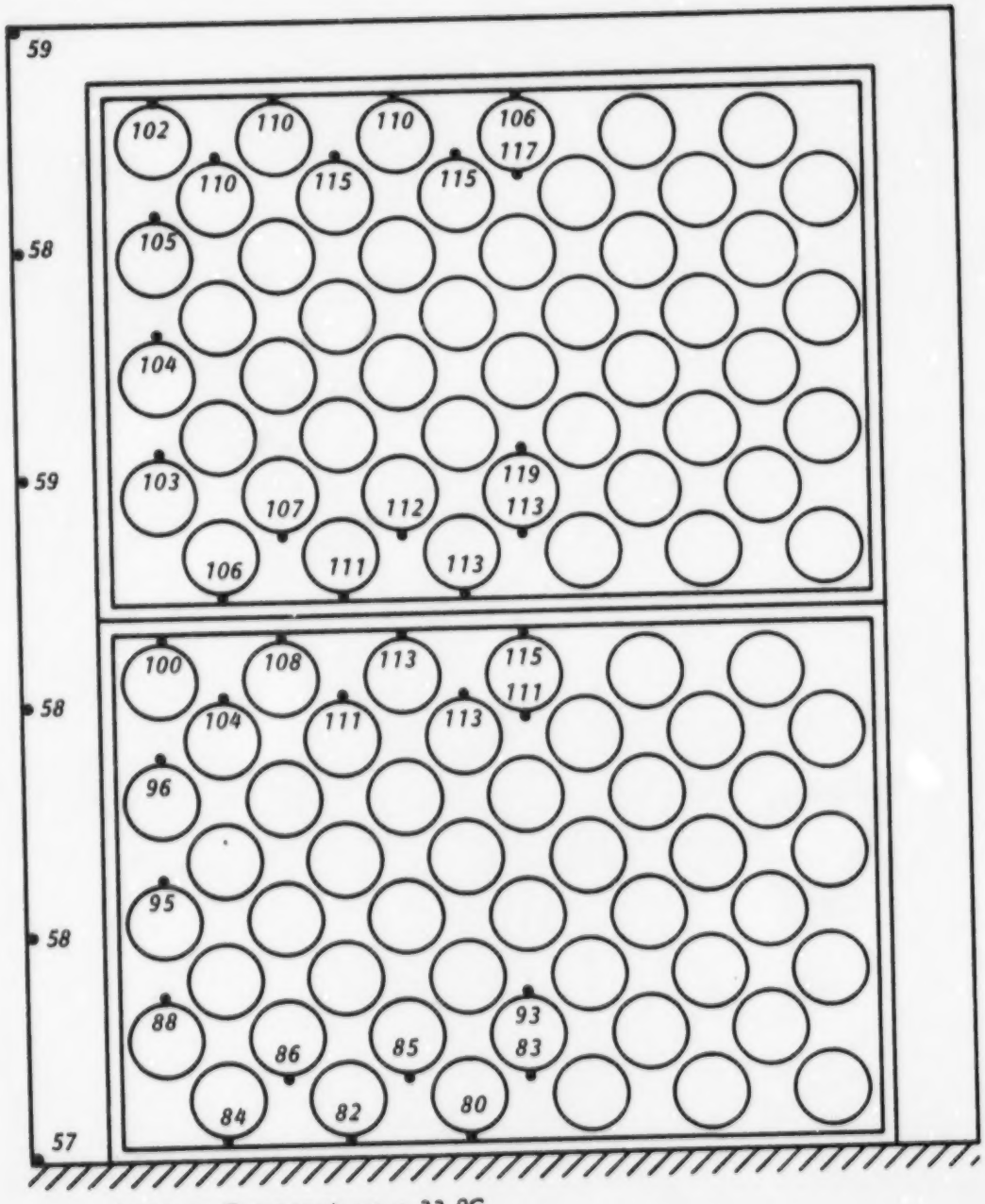
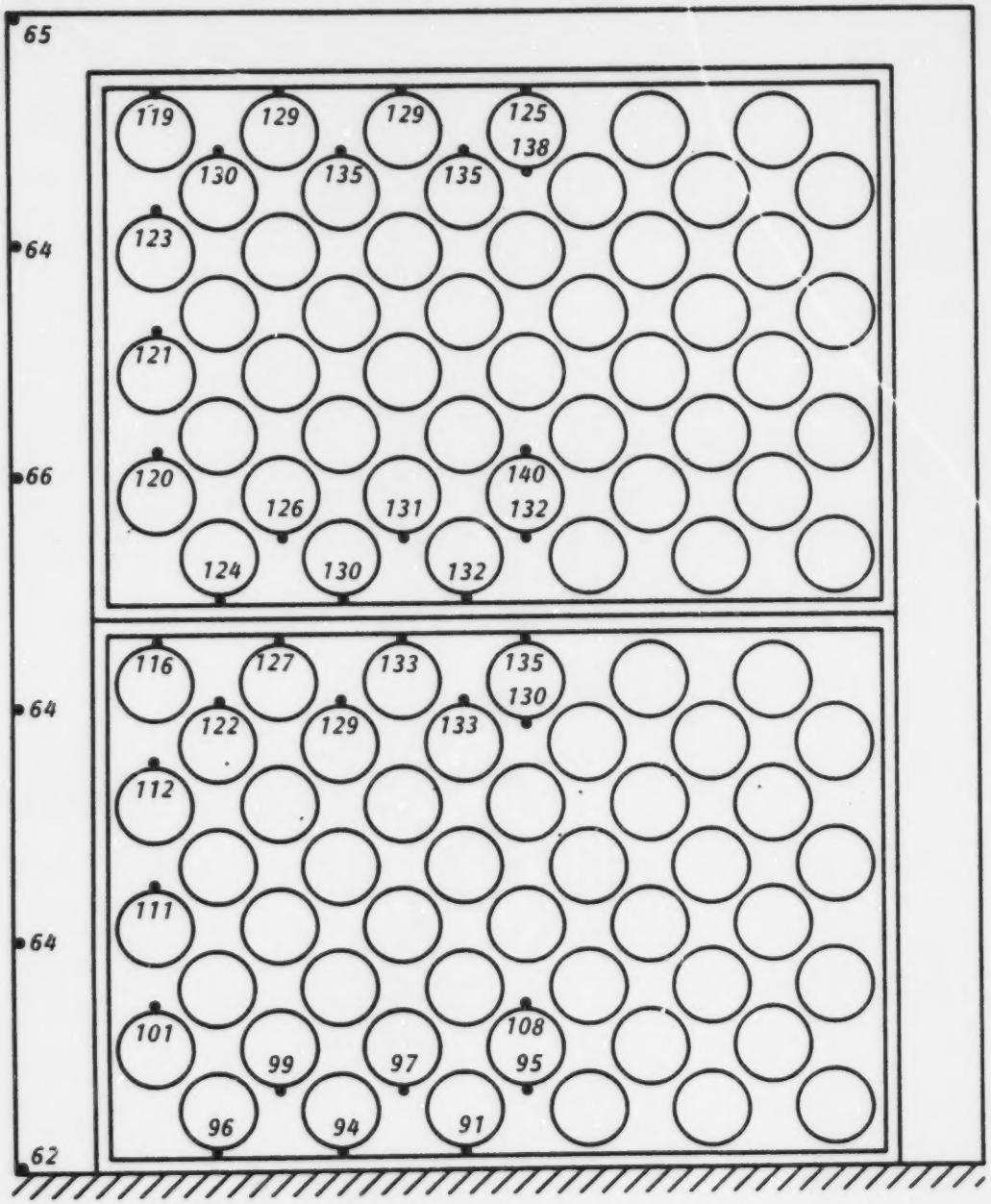


FIGURE 13

TEMPERATURE MEASUREMENTS (°C) AT 15 W/BUNDLE
WITH AIR AND NO IMPACT LIMITER



Ambient Temperature = 24 °C

FIGURE 14

TEMPERATURE MEASUREMENTS (°C) AT 20 W/BUNDLE WITH AIR AND NO IMPACT LIMITER

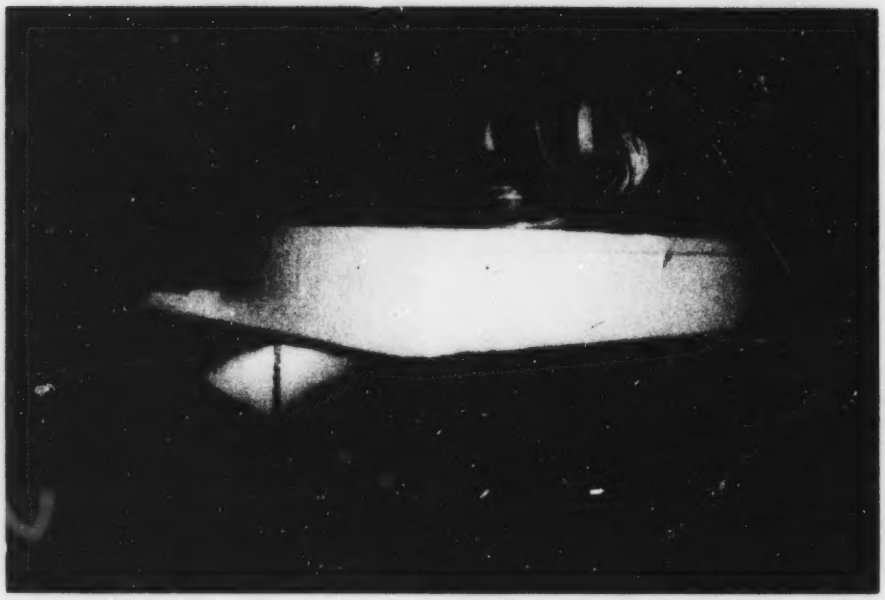


FIGURE 15
SIMULATED CASK WITH IMPACT LIMITER

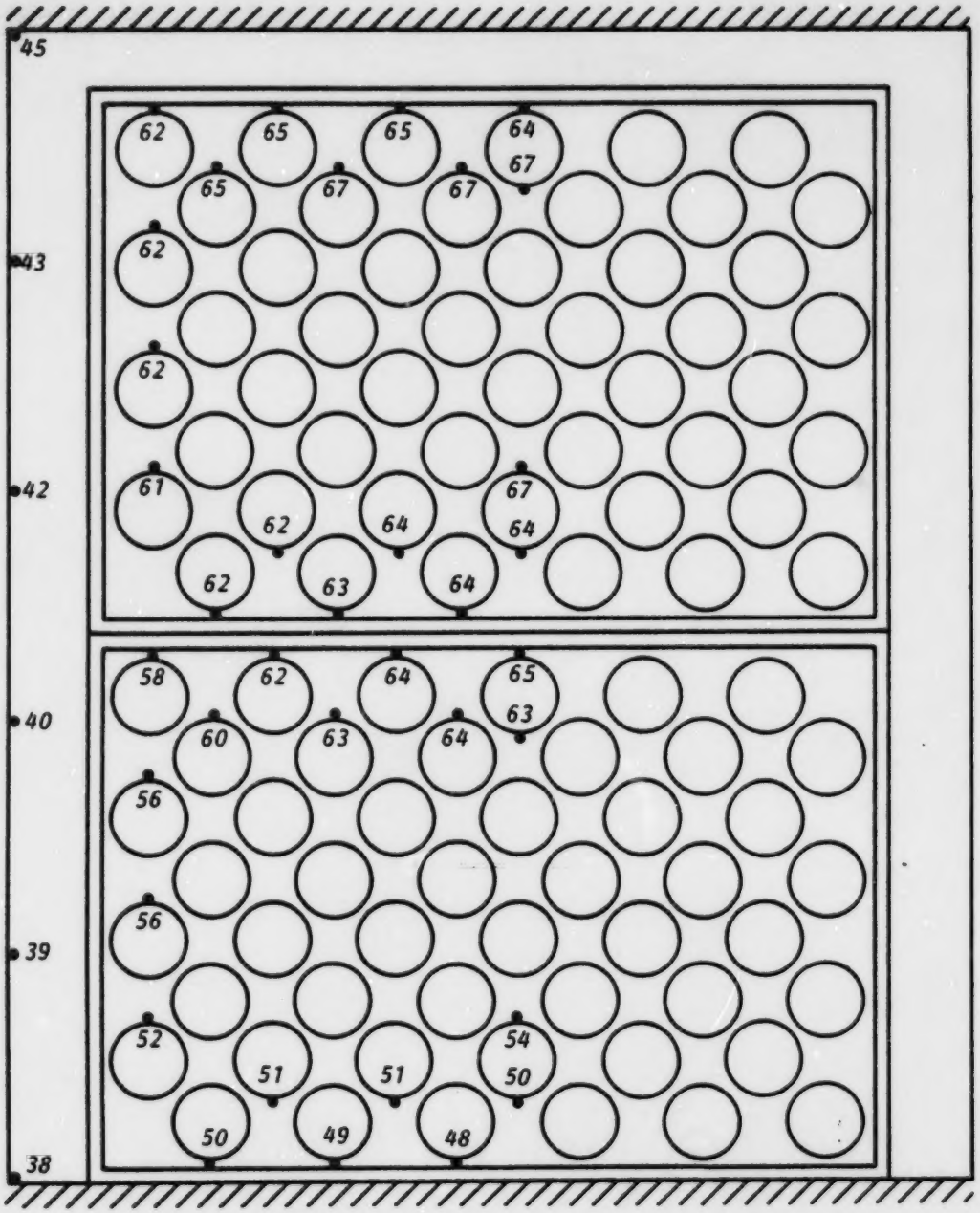


FIGURE 16

TEMPERATURE MEASUREMENTS (°C) AT 5 W/BUNDLE
WITH AIR AND IMPACT LIMITER

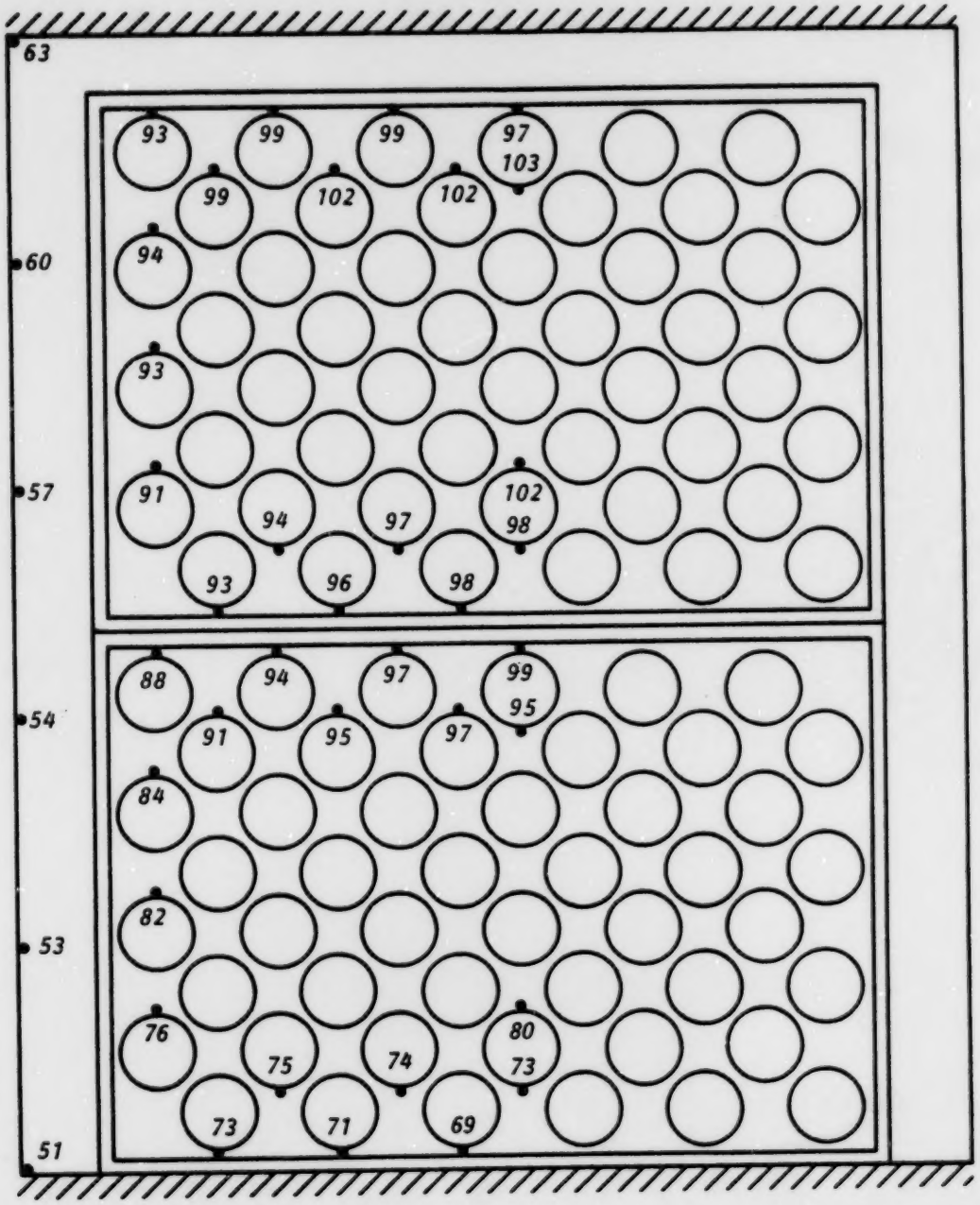
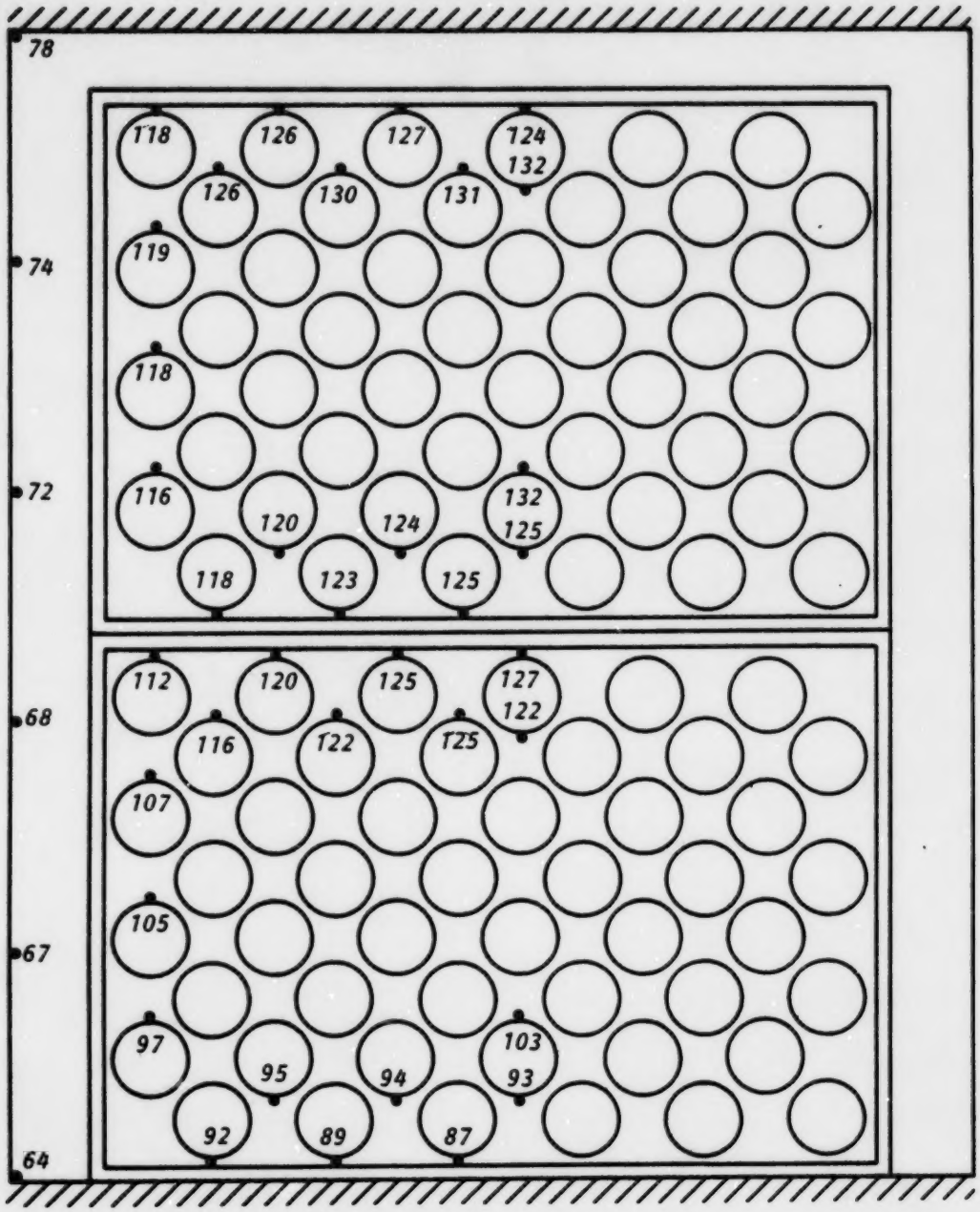


FIGURE 17

TEMPERATURE MEASUREMENTS (°C) AT 10 W/BUNDLE
WITH AIR AND IMPACT LIMITER



Ambient Temperature = 31 °C

FIGURE 18

TEMPERATURE MEASUREMENTS (°C) AT 15 W/BUNDLE WITH AIR AND IMPACT LIMITER

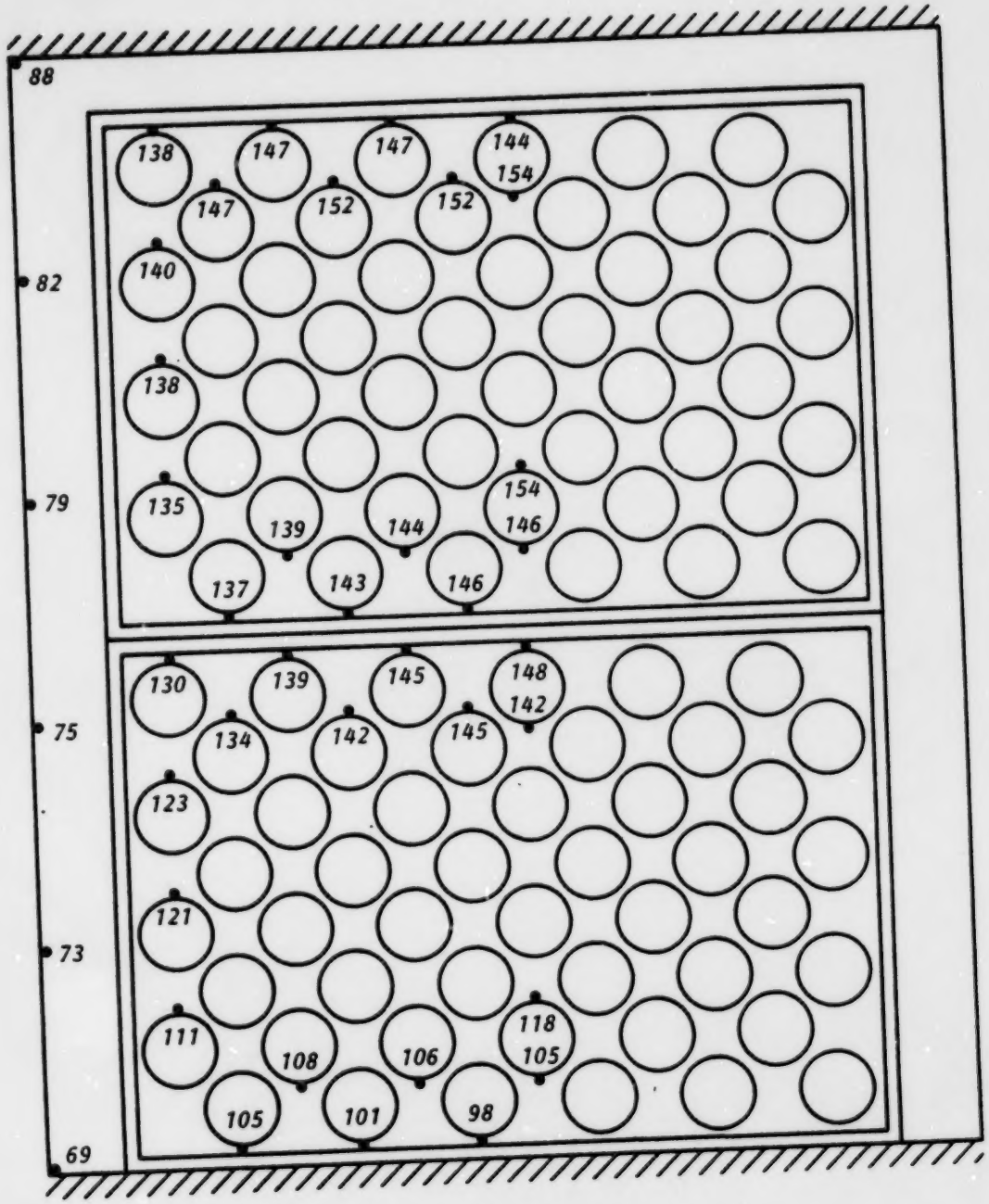
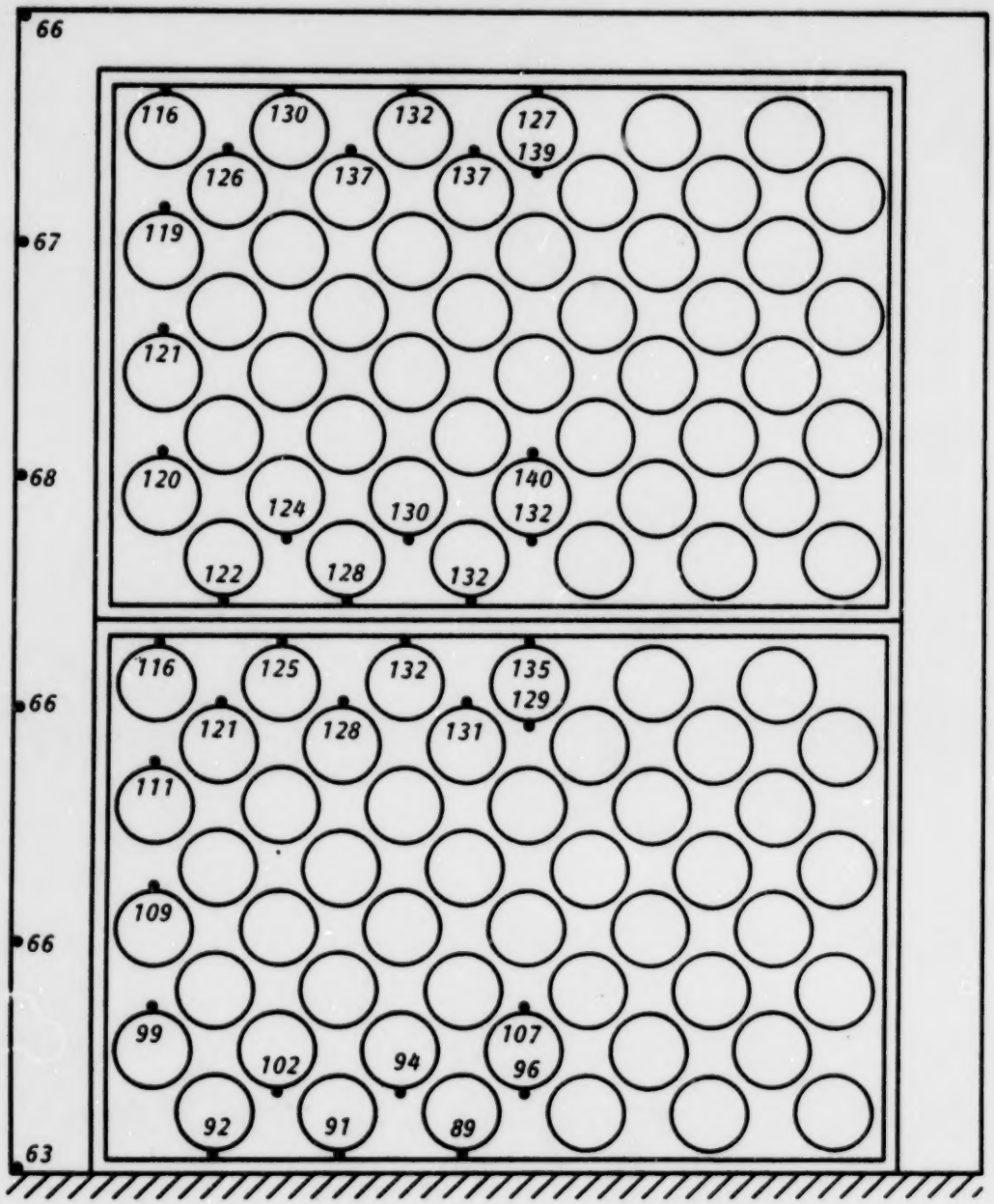


FIGURE 19

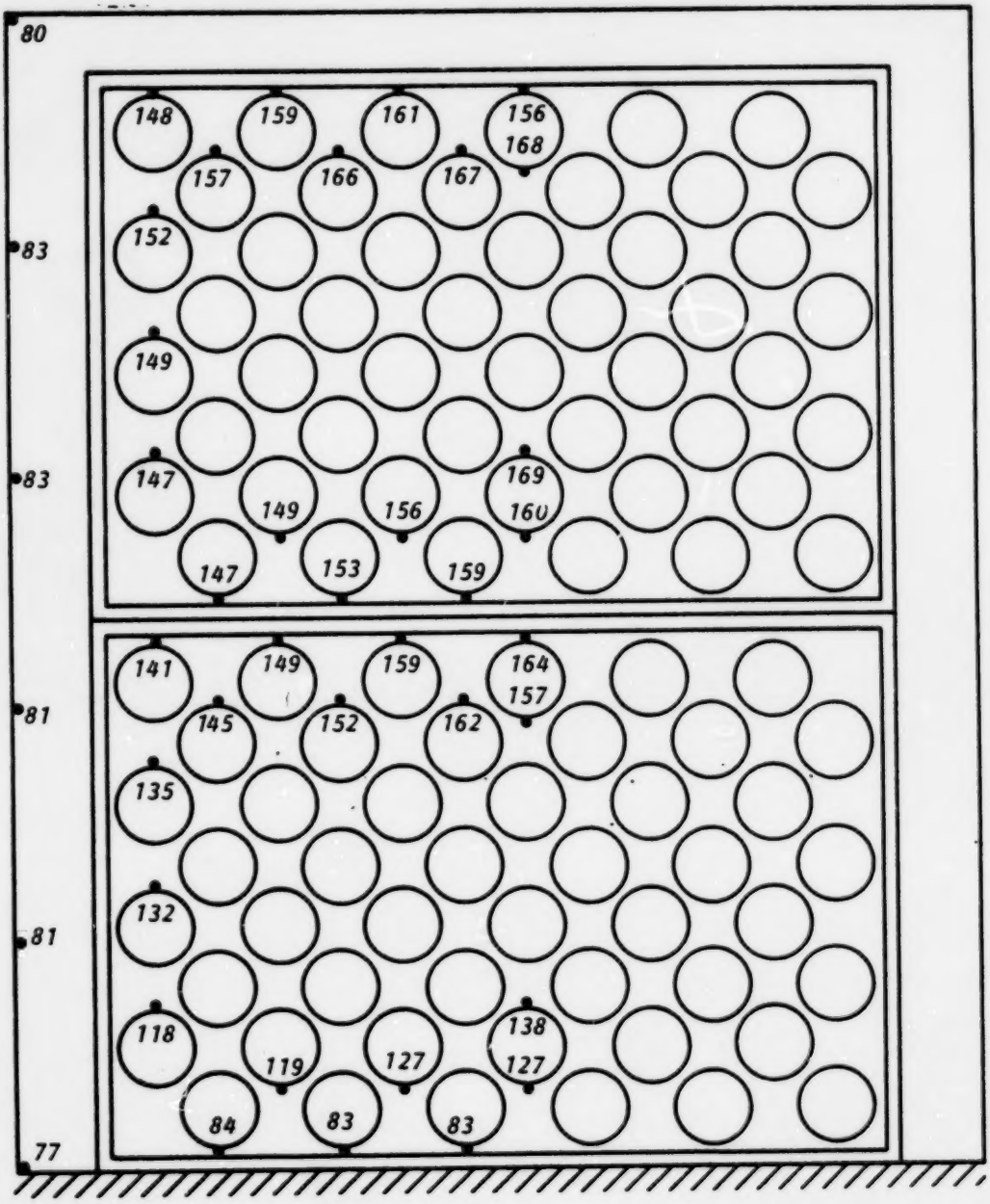
TEMPERATURE MEASUREMENTS (°C) AT 20 W/BUNDLE
WITH AIR AND IMPACT LIMITER



Ambient Temperature = 27 °C

FIGURE 20

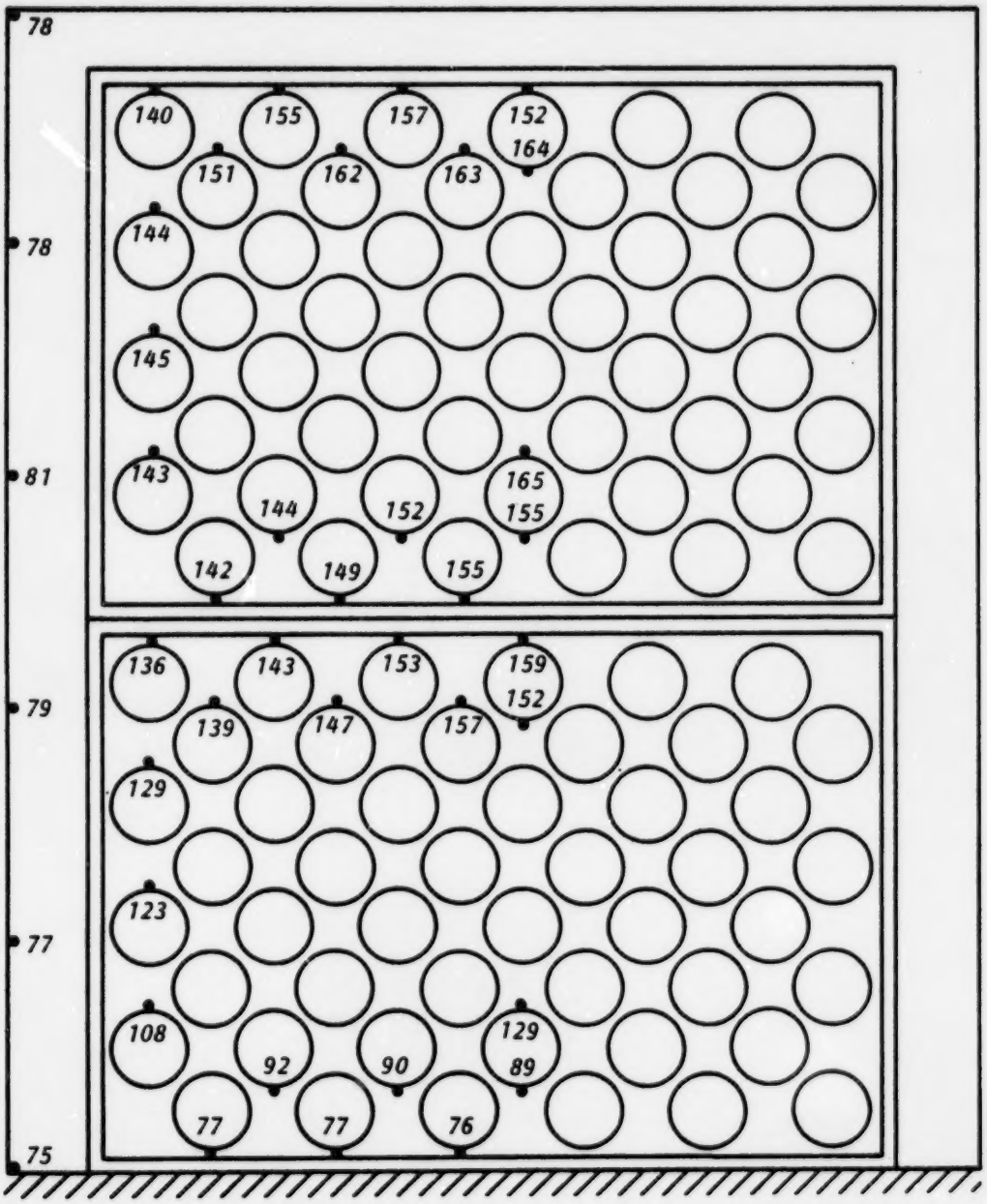
TEMPERATURE MEASUREMENTS (°C) AT 20 W/BUNDLE WITH 20 LITRES OF WATER AND NO IMPACT LIMITER



Ambient Temperature = 27 °C
Cavity Pressure = 42 kPa

FIGURE 21

TEMPERATURE MEASUREMENTS (°C) AT 30 W/BUNDLE WITH 60 LITRES OF WATER AND NO IMPACT LIMITER



Ambient Temperature = 24 °C
Cavity Pressure = 50 kPa

FIGURE 22

TEMPERATURE MEASUREMENTS (°C) AT 30 W/BUNDLE COMPLETELY FILLED AND DRAINED AND NO IMPACT LIMITER

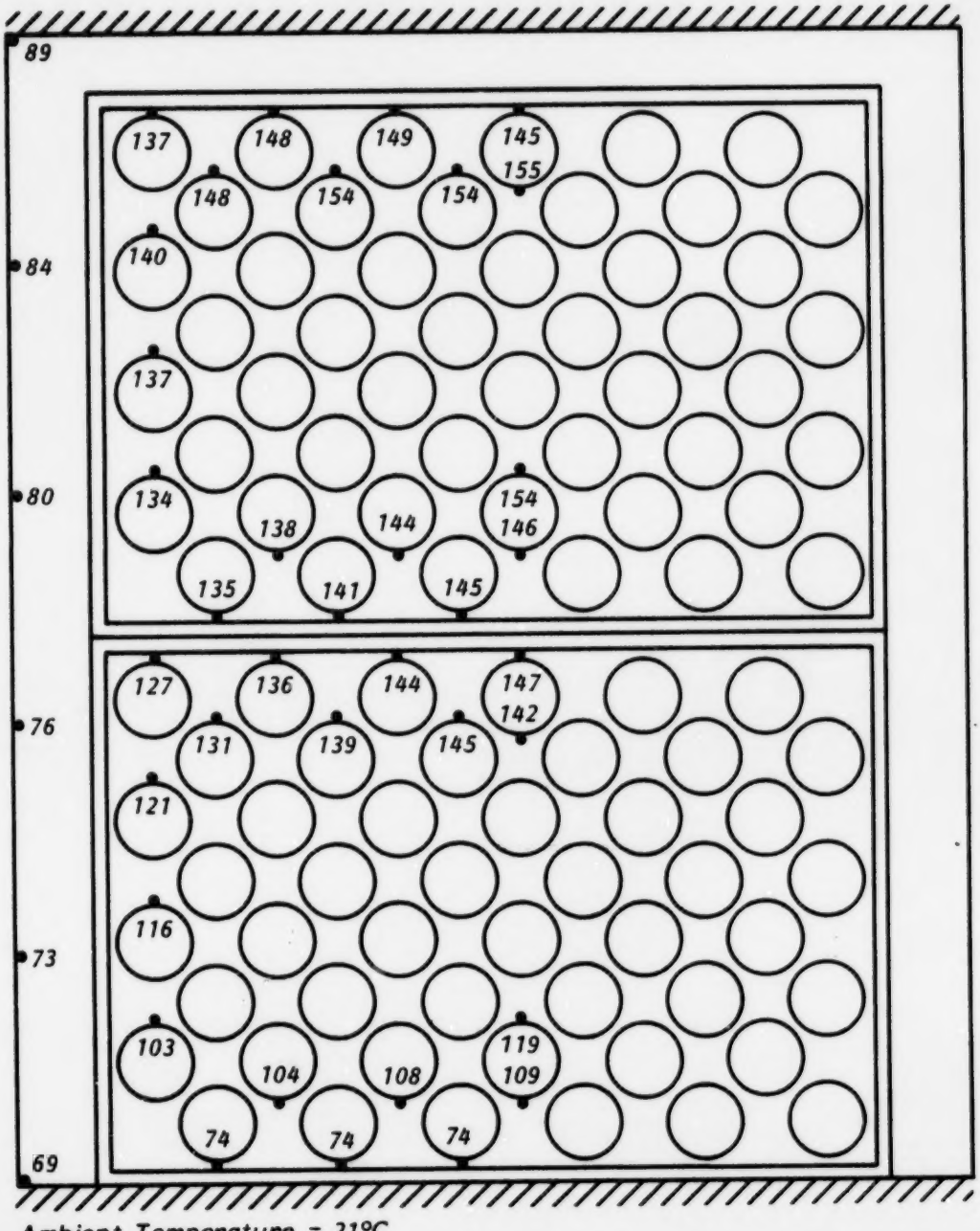


FIGURE 23

TEMPERATURE MEASUREMENTS (°C) AT 20 W/BUNDLE
WITH AIR, IMPACT LIMITER AND WEATHER COVER

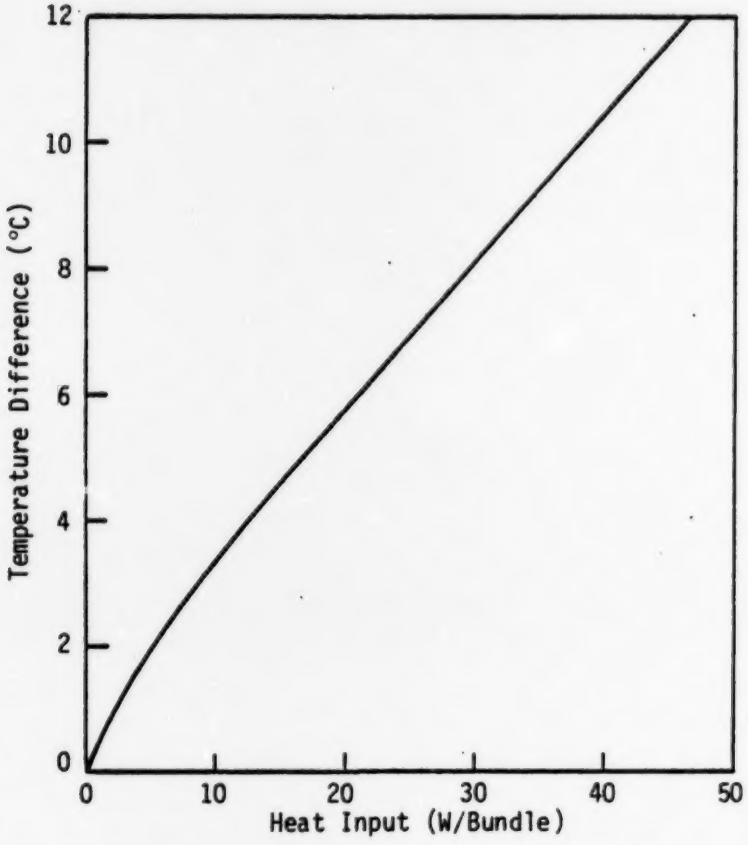


FIGURE 24

TEMPERATURE DIFFERENCE BETWEEN MAXIMUM FUEL SHEATH TEMPERATURE AND AVERAGE MODULE TUBE/FUEL BUNDLE TEMPERATURE

TABLE 1
SUMMARY OF TEMPERATURE RESULTS

Test Description	Heat Input (W/Bdle)	Temperature (°C)			
	$\dot{Q}$	T_a	T_w	T_T	T_F
Air Test Without Impact Limiter	5	21	34	60	62
	10	23	47	92	96
	15	23	58	119	124
	20	24	64	140	146
Air Tests With Impact Limiter	5	21	41	67	69
	10	22	56	102	106
	15	31	70	132	137
	20	23	78	154	160
Air-Water Tests Without Impact Limiter (20 Litres)	20	27	66	140	--
Air-Water Tests Without Impact Limiter (60 Litres)	30	27	81	169	--
Air-Water Tests Without Impact Limiter (Filled and Drained)	30	24	78	165	--
Air Tests With Impact Limiter and Weather Cover	20	21	78	155	161

T_a = Ambient Temperature

T_W = Average Cask Wall Temperature

T_T = Hottest Module Tube Temperature

T_F = Maximum Fuel Sheath Temperature